Spatial Variability of Litter Gaseous Flux Within a Commercial Broiler House: Ammonia, Nitrous Oxide, Carbon Dioxide, and Methane[1]

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ABSTRACT Twenty-eight flocks were grown on litter in a tunnel-ventilated, curtain-sided commercial broiler house prior to this summer flock. Grid measurements were made using a photo-acoustic multigas analyzer to assess the spatial variability of litter gases (NH_3, N_2O, CO_2, and CH_4) on d 1 and 21. The pooled results for the brood and non-brood areas of the house were 1) NH_3 flux was greatest in the brood area at d 1, averaging 497 mg/(m^2•h), and had a mean of 370 mg/(m^2•h) in the vacant end of the house; 2) at d 21, the non-brood area had the greater average NH_3 flux, 310 mg/(m^2•h), and flux in the brood area was 136 mg/(m^2•h); 3) N_2O and CH_4 fluxes were <60 mg/(m^2•h); and 4) on d 1, brood CO_2 flux was 6,190 mg/(m^2•h) compared with 5,490 mg/(m^2•h) at the opposite end of the house. On d 21, these values increased to 6,540 and 9,684 mg/(m^2•h) for the brood and non-brood areas. Ammonia flux seemed most affected by litter temperature. Carbon dioxide and CH_4 increased from placement to mid growout, corresponding to increased moisture, especially near the fans. Contour plots were developed using geostatistical software to visually assess the spatial disparity among the measurements. This research provides a unique view of gas flux variation within the house. Collinear factors such as house management, bird size and age, and amount of deposition are significant factors for litter gas flux and should be considered in comprehensive models for emission estimates.

Key words: ammonia, broiler, gas flux, litter

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INTRODUCTION

Poultry feeding operations are comprised of multi-faceted physical, chemical, and biological systems that affect gaseous emissions from the farm. Diurnal, seasonal, life cycle, and management variations exist in feeding, digestion, excretion, and poultry site activity. Housing structures vary as well. The confluence of these factors in conjunction with different climates and topographies around the country make a "one-size-fits-all" emission model extremely difficult to develop. Although new research reports are emerging for US farms, the emission rates for NH_3 have been determined using different methodologies and a range of conditions, such as multiple bird and litter ages through various seasons. Gas concentration data have been published from research conducted in broiler houses in Texas (Redwine et al., 2002), Georgia (Worley et al., 2002), Mississippi (Miles et al., 2004), Kentucky, and Pennsylvania (Wheeler et al., 2003). The NRC (2003) suggested that combining these findings to produce an average emission measurement could cause over- or underestimation of emission rates.

Ammonia emissions from poultry operations receive the most negative attention with regard to gaseous pollutants. The Clean Air Act establishes a threshold emission limit of 100 tons/yr of any air pollutant. Ammonia is regulated in the Clean Air Act, not as one of the 6 criteria pollutants, but as a precursor to particulate formation. However, both the Comprehensive Environmental Response, Compensation and Liability Act (also known as Superfund) and the Emergency Planning and Community Right-to-Know Act have reporting requirements of 100 lb of NH_3/d or 18.3 tons/yr, a level that may affect large animal production facilities (NRC, 2003). At present, no air pollutant emission rate has been promulgated specifically for or applied to animal production.

Recently, the Environmental Protection Agency published the National Emission Inventory-Ammonia Emissions from Animal Husbandry Operations, Draft Report (Environmental Protection Agency, 2004), estimating annual NH_3 emissions by animal group for each county in the United States. The NH_3 inventory was revised because of concerns raised by the NRC (2003) that recommends a process-based, mass-balance approach to estimate emissions. Several years of research may be necessary to develop sufficient data for this type of modeling. The NRC

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report summary indicates that limited data have been published about NH_3 emission factors, imparting an inability to account for seasonal and regional influences on NH_3 emissions from animal production. Eight data points were cited for developing an NH_3 emission factor for broiler houses (0.22 lb of NH_3/yr per head), and these points were primarily based on European facilities (NRC, 2003). Producers in the US should expect higher factors with litter reuse, whereas many European producers clean out between flocks.

Science-based emission factors for US animal production systems are lacking. Emission-specific measurement and control strategies as well as management techniques are needed. The technology available for determination of real-time, continuous concentrations of NH_3 cannot withstand the harsh environment of the broiler facility. Ammonia detection equipment, such as electrochemical technology, may deplete in the broiler house air in a matter of hours (unpublished data). Highly accurate technologies, such as chemiluminescent and photo-acoustic methods, are cost prohibitive for single grower use (Gates et al., 1997).

An emission factor expresses the amount of gaseous pollutant emitted from an animal production facility over a period of time. However, these factors are subject to the accuracy of the measurement technology. Emission factors are generally determined using the average concentration of the pollutant near the house exhaust fans and the volume of air that has passed through the building. Obtaining this information is not trivial. A recent report estimates 632 mg of NH_3 per bird/d (Lacey et al., 2003). The NRC (2003) factor of 0.22 lb of NH_3/yr per head in equivalent units is 274 mg of NH_3 per bird/d, but even on a single broiler farm, house-to-house variation can be high (Wheeler et al., 2003). Still, emission factors represent the favored empirical approach for emissions estimates at present, and comprehensive models based on chemical, physical, and biological processes continue to develop.

The objective of this work was to assess the spatial variability of litter gas products (NH_3, N_2O, CO_2, and CH_4) within the broiler house during a summer flock on d 1 and 21. Flux measurements are estimated using the difference in gas concentration at an initial and a later time using an enclosed chamber. The units of estimated flux values are mass of pollutant gas per area per time. Although one could easily convert the flux estimate to an emission factor using stocking density (area per bird) and the appropriate time extension (such as hour to day or year), the conversion is counterintuitive because the number of birds should increase to decrease the emission factor. Thus, this work is not applicable to emission factors, but provides a picture of the gas flux variability within the house with concurrent measurement of litter temperature and subsequent correlation to litter pH and moisture. Further work will incorporate analyses of litter composition into the desired comprehensive models for litter mass balance.

MATERIALS AND METHODS

One-day-old chicks were placed in a tunnel-ventilated, curtain-sided commercial broiler house and were confined to the brood end of the house. Twenty-eight flocks had been grown on the litter prior to this flock, which was grown during the summer in Mississippi. The poultry grower performed routine preparation of the house prior to bird placement: litter was decaked using a Lewis Bros. Housekeeper (Baxley, GA), no litter amendment was added, the brood area of the house was heated to a nominal temperature of 32.2°C, and feed and water were provided. Approximately, 26,700 chicks were placed for the growout measurements described.

Gas measurements, using a photo-acoustic multigas analyzer in conjunction with flux boxes, began about 6 h after chick placement on d 1. Measurements were repeated at d 21. The multigas analyzer (Innova 1312, California Analytical, Orange, CA) uses photo-acoustic infrared detection techniques. A self-contained pump draws air into the machine where the sample is sealed in the analysis cell. Infrared light is reflected off a mirror and passed through a mechanical chopper, which pulsates it through the appropriate optical filter. As the light is transmitted through the filter, the chosen gas selectively absorbs it, causing the gas temperature to rise as well as fall with the pulsating light. The pressure of the gas in the closed cell is an acoustic signal that is measured by 2 microphones and is directly proportional to the concentration of the gas. A wheel rotates the optical filters to obtain each gas concentration during a measurement cycle. When all gases are selected for analysis, the cycle duration is approximately 70 s. The analyzer is configured to measure NH_3, CO_2, CO, N_2O, CH_4, and water vapor.

Approximately 2 s before the analyzer drew in a sample (time-zero concentration), a flux box was inverted on the litter surface; the second sample was captured after 70 s. The difference between the concentrations at time zero and 70 s was used along with the ideal gas law to estimate gas flux from the litter. Flux boxes (similar to Ferguson et al., 1998) were cylindrical plastic containers, 35 cm high with a 14.3-cm radius; a small electric fan was mounted inside the bottom of each container. The analyzer was connected to the flux box by a 0.635-cm diameter tube with a length of 1.07 m. Before the 1-min reading was taken, the fan mixed the air in the flux box for 10 s (Moore et al., 1997). The short sampling interval was used so that the microclimate of the litter changed as little as possible, an attempt to obtain an accurate measurement of the instantaneous litter flux.

Thirty-six sampling positions composed an imaginary grid (Figure 1), where measurements were placed at 3 locations across the house (5 m apart) and 12 locations down the house (12 m apart). The house dimensions were 12.8 m × 146.3 m. Approximately 2 h were required for sampling the entire house. To exclude potential areas of bias, high traffic areas near feeders and waterers, with greater manure deposition, feed wastage, and typically higher moisture, were not sampled during the current

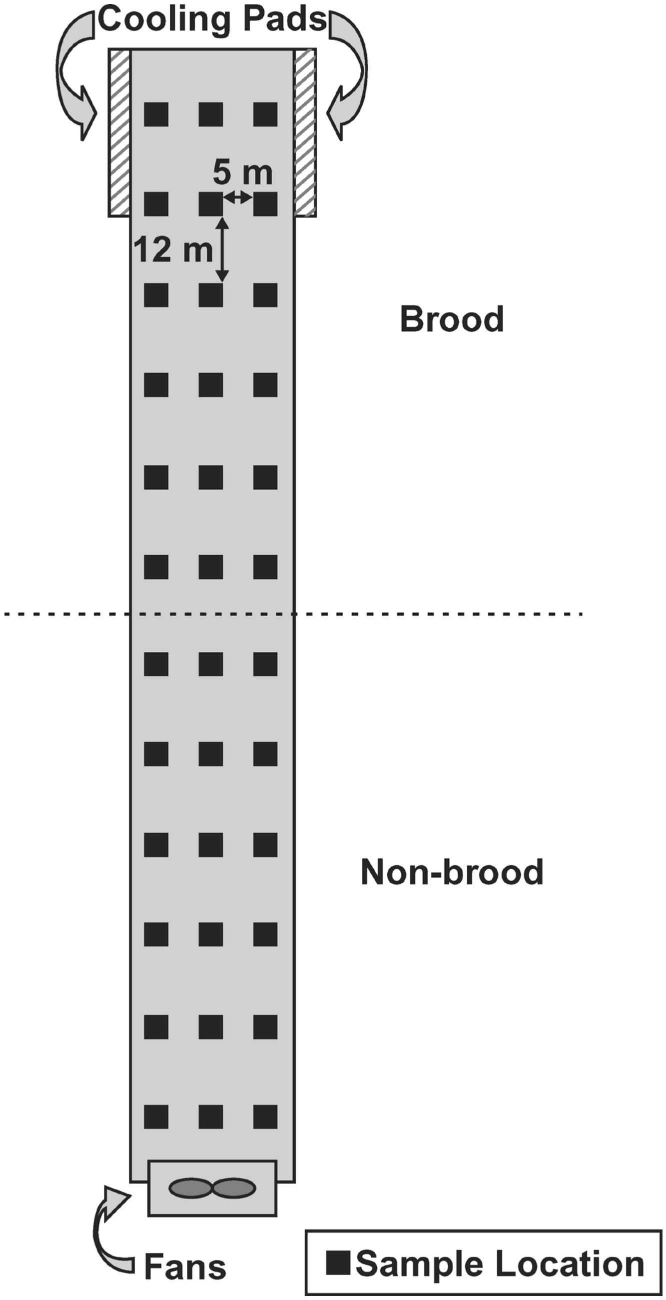

Figure 1. Broiler house sampling grid layout.

study. Greater manure and feed spillage could contribute more N to the litter in these areas, creating a greater potential for NH_3 volatilization.

As gas measurements were carried out, litter surface temperature was concurrently measured using a laser infrared thermometer (Raytek Corporation, Santa Cruz, CA). The upper 10 cm of the litter were collected at each sample position and transported back to the laboratory for determination of moisture and pH. A litter to deionized water ratio of 1:5 was used to determine pH on a subsample of "as is" litter. Litter samples were dried for 48 h at 65°C to find moisture content by loss in weight.

The grid sampling technique used here to verify the spatial variability of the litter gas flux and litter properties does not lend itself to traditional statistical analysis; the variables (measurements) were not random and were biased based on location in the house. Contour plots or variograms were developed to assess the spatial disparity among the measurements visually. The geostatistical software (Golden Surfer 8, Golden, CO) used the method of kriging, a statistical linear method estimating the best value based on weighted linear combinations of neighboring values while aiming to minimize the error variance between samples. The variograms present a snapshot of the variation in litter gas flux or properties for a particular time during the growout. Litter characteristics between the sample points were mathematically derived (by kriging) to complete the profile over the floor surface.

RESULTS AND DISCUSSION

Temperature, pH, and moisture are recognized as major contributors to NH_3 loss from broiler litter (Elliot and Collins, 1982; Carr et al., 1990). These litter properties, as well as the gas flux estimates, are represented by contour plots in Figure 2, but are given as pooled results for the brood and non-brood area of the house in Table 1. The litter temperature profile for d 1 (Figure 2) clearly demonstrates the management practice of half-house brooding. In modern broiler rearing, chicks at placement can be confined to one-half of the house. Heating only one-half of the house saves money, and during the early stages of the growout, the chicks do not require the space of the entire house. The duration of heat provided by the grower, usually 7 to 12 d, is subject to the outside temperature. The range of litter temperatures for both d 1 and 21 were similar, 27.4 to 30.7°C and 27.8 to 30.2°C, respectively. However, the litter temperature was greater in the non-brood area of the house at d 21 (Figure 2). Litter temperature exhibited fewer anomalies (localized lows or highs) compared with all other parameters.

Litter pH was lower in the brood portion of the house at both sampling dates when compared with the non-brood end of the house. The overall range of pH values at d 21 was lower than at d 1, possibly a result of more fresh manure deposition from the older birds. From d 1 to 21, litter moisture in the brood area increased from 22.7 to 23.4% and, in the non-brood area, increased from 23.4 to 25.5% (Table 1). The variogram shows an area of high moisture (>35%) at d 1 that was present near the sidewall (Figure 2). This was thought to result from water seepage into the pad from a low-lying area outside the house and recent heavy rains. Ammonia flux (discussed in more detail subsequently) was not maximized in this high moisture area. Areas where litter becomes anaerobic (such as where litter moisture is high) are areas of suppressed NH_3 volatilization (Carr et al., 1990).

Ammonia flux was greatest during this summer flock measurement in the brood area at d 1, averaging 497 mg/(m^2·h) and had a mean of 370 mg/(m^2·h) in the vacant end of the house (Table 1). At d 21, the non-brood end of the house had the greater average NH_3 flux, 310 mg/(m^2·h) vs. 136 mg/(m^2·h) in the brood area. This "switch"

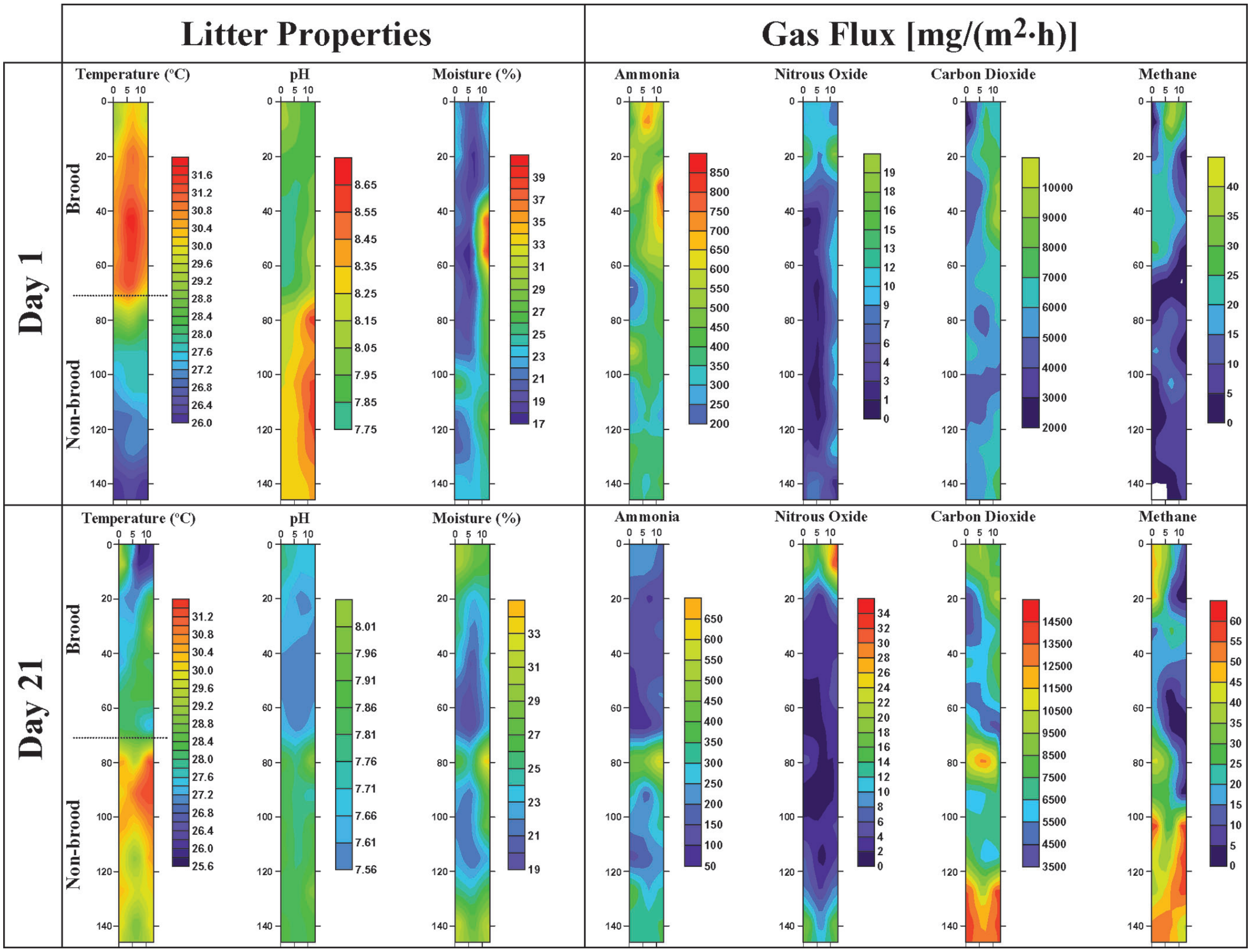

Figure 2. Variograms of litter properties and gaseous flux (NH_3, N_2O, CO_2, and CH_4) in a curtain-sided, commercial broiler house during a summer flock at d 1 and 21.

in the region of the house with the greater NH_3 flux (i.e., the non-brood end) is similar to the change observed in litter temperature for the 2 measurement days. Brewer and Costello (1999) found a mean NH_3 flux of 208 mg of NH_3 N/(m^2•h) using a dynamic flow chamber on reused rice hull litter (maximum 6 flocks). Considering that the current study had 28 flocks on reused pine shavings litter and that a static chamber technique was used, the magnitude of the NH_3 flux in the current study appears reasonable.

The NH_3 flux contour plot for d 1 (Figure 2) shows 3 areas of greater flux in the brood area. The middle of the house near the end wall and at each side of the house near the end of the cooling pads exhibited fluxes in excess of 550 mg/(m^2•h). These were thought to be areas of stagnant airflow, but this cannot be said with certainty because airflow measurements were not obtained during the gas and litter sampling. At d 21, the NH_3 flux was elevated slightly near the fans, which was an area of high moisture. One area near the sidewall had the largest flux

Table 1. Pooled litter gas flux and property measurements for the brood and non-brood areas of the broiler house

		Litter property			Litter gas flux [mg/(m^2•h)]			
Bird age	Location	Temperature	pH	Moisture	NH_3	N_2O	CO_2	CH_4
		(°C)		(%)				
1 d	Brood	30.7	7.9	22.7	497	7.4	6,190	14.7
	Non-brood	27.4	8.4	23.4	370	4.2	5,490	7.3
21 d	Brood	27.8	7.6	23.4	136	6.4	6,540	17.1
	Non-brood	30.2	7.9	25.5	310	5.6	9,684	42.8

at this date [about 600 mg/(m^2•h)], which corresponded to high moisture, pH, and temperature.

Nitrous oxide flux from the litter was low, 2 orders of magnitude lower than NH_3 flux. An insignificant increase was observed overall from d 1 to 21, 5.8 vs. 6.0 mg/(m^2•h), the average of the brood and non-brood regions for the respective dates (Table 1). Similar to NH_3, the greatest overall N_2O flux [7.4 mg/(m^2•h)] was observed at d 1 in the brood area. Regarding the spatial variability of the N_2O (Figure 2), variograms indicate areas of increased flux near the ends of the house and at the sidewalls. Nitrous oxide is a preliminary product in the denitrification portion of the N cycle (Prescott et al., 2002). Denitrification is the anaerobic process by which NO_3^- is converted to nitrogen gas. The microbes involved in this process are aerobic organisms, but use nitrate as the terminal electron acceptor in the absence of oxygen. Because these measurements are carried out at the litter surface, one would expect these flux values to be low. In constrast, the aerobic population of uric acid decomposers seems more essential to NH_3 volatilization than anaerobic organisms (Schefferle, 1965).

Methane flux, like N_2O flux, was low (Table 1): brood and fan areas at d 1 were 14.7 and 7.3 mg/(m^2•h), and brood and fan areas at d 21 were 17.1 and 42.8 mg/(m^2•h). Thus, there was increase in CH_4 flux over time with the greatest flux observed in the non-brood area of the house on d 21. Methane can be produced from organic matter degradation or from the combination of CO_2 and H (inorganic substrates); both processes are anaerobic. Thus, we do not expect significant CH_4 flux at the litter surface. The results for low levels of N_2O and CH_4 are consistent with an emission study by Wathes et al. (1997), which found low levels of these gaseous constituents.

Carbon dioxide levels in the broiler house atmosphere tend to increase over time with bird growth and respiration. Carbon dioxide is also a product (at several stages) of the aerobic breakdown of uric acid (Carlile, 1984). In a manure drying study, Mahimairaja et al. (1990) found that CO_2:NH_3 released was less than expected from the breakdown of uric acid and supposed that either an increase in CO_2 resulted from the decomposition of other organic compounds or that microbes reimmobilized the NH_3 and the NH_3 was reabsorbed by the manures. As such, CO_2 is an important component of the litter gas flux picture. Brood CO_2 flux was 6,190 mg/(m^2•h) compared with 5,490 mg/(m^2•h) in the opposite end of the house (Table 1). On d 21, these values increased to 6,540 and 9,684 mg/(m^2•h) for the brood and non-brood areas. Again, we see the largest flux for CO_2 on the fan end of the house at d 21, similar to the "switch" discussed previously for litter temperature and NH_3 at this date.

The aforementioned results presented NH_3, N_2O, CH_4, and CO_2 flux from broiler litter on d 1 and 21 of a summer flock, comparing pooled results from the brood and non-brood areas of the house. Also, contour plots depicted an integrated surface derived from 36 individual measurements over the litter. Use of the photoacoustic technology allowed simultaneous measurement of the gases of interest. Ammonia flux, which was greatest for the brood area on d 1, seemed most affected by temperature. Carbon dioxide and CH_4 increased from placement to mid growout and corresponded to increased moisture, especially near the fans. This research is in its infancy, but provides a unique view of gas flux within the house. Complex interrelationships exist among the measured litter properties. It is likely that physical properties of the litter that affect gas production are unidentified as yet. For example, the role of cake formation, amount of cake, etc., and litter gas flux have not been quantified nor have the characteristics where the litter remains friable. Further work should include multiple bird ages, different housing structures, seasonal measurements, inclusion of the ventilation and microbial profiles, and finally development of a comprehensive N mass balance.

Little science-based data exist on the emission potential of agricultural sources. Technologies used to determine emissions should be verifiable, and predictive models must be applicable to a wide range of conditions. A number of existing statutes, such as the Clean Air Act; the Comprehensive Environmental Response, Compensation and Liability Act; and the Emergency Planning and Community Right-to-Know Act, overlap to govern allowable emission levels for farms, and application to animal agriculture is imminent. Until a credible model for emission rates resulting from sufficient science-based data is available for US poultry producers, permitting activities remain unsupported.

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